



HHS Public Access

Author manuscript

Dev Sci. Author manuscript; available in PMC 2023 January 01.

Published in final edited form as:

Dev Sci. 2022 January ; 25(1): e13147. doi:10.1111/desc.13147.

Amount and Type of Physical Activity as Predictors of Growth in Executive Functions, Attentional Control, and Social Self-Control Across Four Years of Elementary School

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Abstract

This paper used a nationally representative sample of children from the U.S. to examine the extent to which physical activity and sports participation may promote growth in children's executive functions, attention, and social self-control over time. Using data from the ECLS-K:2011 ($N=18,174$), findings indicated that regular physical activity predicted growth in executive functions and attention from 3rd to 4th grade ($\beta s = .03 - .05$) but not from kindergarten to 1st grade. After controlling for the frequency of physical activity, participation in group sports predicted increases in executive functions, attention, and social self-control during both periods ($\beta s = .02 - .04$). Though modest in size, the findings suggest that encouraging children to engage in more frequent and more team-based activity will benefit the development of their executive functions and related skills, and especially so for children in middle childhood.

Keywords

executive function; self-regulation; physical activity; exercise; sport

Children's executive functions show consistent links to later achievement, both in elementary school (Blair & Razza, 2007; Duncan et al., 2007; Morgan, Farkas, Hillemeier, et al., 2019; Nguyen & Duncan, 2019) and in high school (Ahmed et al., 2019). In turn, deficits in executive functions predict increased risk of continued academic difficulty (Morgan, Farkas, Wang, et al., 2019). Educators and policymakers may therefore seek to target these skills as points of intervention for school success (Blair & Raver, 2015). One potential means of promoting children's executive functions is to increase their amount or type of engagement in regular physical activity (Donnelly et al., 2016), a possibility we examine in this study.

Executive functions are the capacities to direct cognition and behavior deliberately (Zelazo, 2015). They have bases in neural systems of the prefrontal cortex (Blair, 2016) and consist of three major components: the ability to inhibit impulsive or inappropriate behavior

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Conflict of Interest Statement: The authors report no conflicts of interest.

Human Subjects and Studies Statement: This study involved the secondary use of a publicly available, de-identified data set.

(inhibitory control), to flexibly shift behavior or modes of thinking according to situational demands (cognitive flexibility), and the ability to hold and manipulate information in the mind (working memory) (Diamond, 2013). Development of executive functions begins in early childhood and extends to adulthood (Best & Miller, 2010).

There is some evidence that the development of children's executive functions is enhanced through their regular physical activity, especially when those activities engage executive functions (Best, 2010). There are two main processes by which this may occur. First, regular physical activity may promote more efficient biological systems such as blood flow and oxygen consumption, thereby enhancing brain functioning (Hillman et al., 2008). Children's physical activity has indeed been found to predict improvement on tasks requiring the management of behavioral responses (Hillman et al., 2014; Hillman et al., 2011). Beyond behavioral responses, children's physical activity has been linked in randomized control trials to favorable changes in brain structure and signaling in areas related to cognitive control (Chaddock-Heyman et al., 2018; Valkenborghs et al., 2019). Most studies have not explicitly considered how these links might differ by developmental period, with many samples of children ranging widely in age (see Tomporowski & Pesce, 2019 for a review). Recent work suggests that physical activity may not benefit young children's executive functions as much as it does those of older children (Cook et al., 2019), though research on this topic in early childhood remains scarce (Carson et al., 2016).

Between the ages of 3 and 6, brain glucose consumption is at its peak (Kuzawa et al., 2014). This has led to the hypothesis that there is a metabolic tradeoff between brain development and physical growth (Kuzawa & Blair, 2019), a notion supported by recent empirical work (Blair et al., 2020). Consistent with such a tradeoff, high levels of physical activity could present a detriment to the development of executive functions (Howard et al., 2016). This suggests that in early childhood, the benefits attributed to physical activity may not emerge in the same way as children move into middle childhood. In fact, for children in kindergarten, motor skill development is more predictive of executive function than is physical activity (Cook et al., 2019). Few empirical studies have examined how these links might differ between early childhood and later in elementary school, a possibility we explore in this study.

The second potential way that children's physical activity may be related to their executive functions is by incorporating complex social and motor demands that require the enactment of self-regulatory skills and provide opportunities to practice them (Best, 2010; Diamond & Ling, 2016; Tomporowski & Pesce, 2019). Participation in sports that require adapting to dynamic contexts and enacting strategies, such as soccer games, shows association with children's executive functions in 3rd grade, whereas participating in sports with more repetitive and predictable contexts such as swimming does not (Becker et al., 2018). Children randomized to a physical activity intervention involving team games experienced significantly better improvements in their cognitive flexibility compared to children randomized to an intervention of just aerobic exercise (Schmidt et al., 2015). Although individual sports have been found to predict growth in these skills in early childhood (Howard et al., 2018), group sports are more likely to be the open-skilled type, with dynamic changing environments rather than repetitive ones, and these show more

consistent links to executive functions and related skills according to a recent systematic review (Gu et al., 2019). These findings suggest that participation in modes of physical activity that engage children's executive functions may promote their development.

In this study, we examined whether the amount and type of regular physical activity longitudinally predict growth in children's executive functions across two developmental periods namely early childhood (kindergarten to 1st grade) and middle childhood (3rd to 4th grade). In population samples such as the one used in the present study, children's physical activity is typically assessed via parental reports rather than direct accelerometry measures. This helps retain generalizability to the broader population for two reasons. First, using objectively measured physical activity via accelerometers requires standardized procedures for collecting and processing data, which may be difficult to accomplish across many sites and thousands of children. Second, current methods for converting accelerometry data to physical activity totals are developed from much smaller samples that may not generalize to the broader population (Pedi i & Bauman, 2015). Although parent reports of children's physical activity are not entirely free from bias, they are more reliable than children's self-reports of their own activity (Trost, 2020). Therefore, parent reports are the preferred method for capturing children's physical activity in a nationally representative sample of children used to generalize to the wider population, and we use them here.

We examined the three core components of executive function (Diamond, 2013): the ability to inhibit automatic responses and manage impulses (inhibitory control), the ability to shift flexibly between tasks or modes of thinking (cognitive flexibility), and the ability to hold and manipulate information in their minds (working memory). In addition to these skills, there are other, closely related skills that also facilitate the enactment of goal directed behavior, namely the ability to focus and manage attention (attentional control) and to engage in emotion regulation and social problem-solving with peers (social self-control) (Bailey & Jones, 2019; Liew, 2012; Nigg, 2017).

These skills might also be called upon in regular physical activity, especially in activities that involve interpersonal and group coordination (Best, 2010). For example, sports activities provide opportunities for children to engage social self-control, such as by coordinating behaviors with other children and developing shared strategies. These abilities are more likely to improve through repeated practice rather than via improved fitness. Because they often involve fast-moving objects and unpredictable opponents, sports activities also require children to attend carefully to both objects and people. Group sports in particular may require processing and coordinating responses to many different demands on children's attentional control and social self-control, in addition to relying on the three core executive functions (Diamond & Ling, 2016). Because attentional control and social self-control are closely related to executive functions (Bailey & Jones, 2019), and because there is reason to believe that sports might engage them and provide opportunity to practice them, we include them with our investigation of children's executive functions.

In the current study, we examined whether the amount and type of children's physical activity predicted increases in their executive functions, attention, and social self-control. We hypothesized that (1) Regular physical activity would predict growth in children's

executive functions over time, and more so for middle compared than early childhood; and (2) Children who engage in group or individual sports would demonstrate growth in executive functions, attention, and social self-control beyond what regular physical activity would predict. To understand how these processes might vary across development, we examined them separately for early and middle elementary school periods. This specificity also offers an important contribution to the current literature, as many studies have not tested for potential developmental differences (Tomporowski & Pesce, 2019), and few have examined the early childhood period at all (Carson et al., 2016).

Method

We used data from the Early Childhood Longitudinal Study-Kindergarten Class of 2010-2011 (ECLS-K:2011) fourth grade public use file (Tourangeau et al., 2018). The ECLS-K:2011 sampled a nationally representative cohort of children in the United States who entered kindergarten in 2011 ($N = 18,174$) using a multi-stage sampling design (see details in: Tourangeau et al., 2018).

Participants

Descriptive statistics for the 18,174 participants in this study are presented in Table 1. In kindergarten, the sample was 51.1% male ($n = 9,288$), and 46.7% of the children ($n = 8,489$) were non-Hispanic White, 25.3% ($n = 4,590$) were Hispanic of any race, 13.2% were Black ($n = 2,397$), 8.5% were Asian ($n = 1,543$), and 4.5% ($n = 826$) identified as two or more races. American Indian or Alaska Native children made up less than 1% of the sample ($n = 168$), as did Native Hawaiian or Pacific Islander children ($n = 117$). The median household income at kindergarten was in the range of \$45,000-\$50,000. The mean age of the children at each wave was 6.12 years old in kindergarten ($SD = 0.37$), 7.11 years old in first grade ($SD = 0.37$), 9.08 years old in third grade ($SD = 0.37$), and 10.08 years old in fourth grade ($SD = 0.37$). About 90% of parent interviews were conducted in English and about 10% in Spanish by bilingual interviewers (Tourangeau et al., 2015).

Measures

Physical Activity

Frequency of physical activity.: To assess the frequency of children's regular physical activity, parents responded to the following question: "In a typical week, on how many days does [your child] get exercise that causes rapid breathing, perspiration, and rapid heartbeat for 20 continuous minutes or more?" (National Center for Education Statistics, 2016). Values ranged from 0-7. This question was developed for the Early Childhood Longitudinal Study, Kindergarten Class of 1998-99 (ECLS-K; Tourangeau et al., 2009).

Sports participation.: In the springs of kindergarten and third grade, parents responded to a series of questions about the types of exercise that their children engage in (National Center for Education Statistics, 2015). Parents indicated yes (1) or no (0) whether their children engaged in any kind of group sports ("e.g., baseball, basketball, soccer, organized or unorganized games in the yard or neighborhood") or individual sports ("e.g., tennis,

swimming, gymnastics”). We created two dichotomous variables to indicate whether children participated in group sports or individual sports.

Executive Functions—The ECLS-K:2011 used both teacher reports and direct assessments to measure different executive functions (Tourangeau et al., 2018).

Inhibitory control.: At kindergarten and first grade, children’s inhibitory control was assessed via teacher ratings of six questions from the inhibitory control subscale of the *Child Behavior Questionnaire Short Form* (CBQ-SF; Putnam & Rothbart, 2006), with responses on a 7-point scale ranging from “extremely untrue” to “extremely true.” A sample item is, “This child can stop him/herself when s/he is told to stop.” In third and fourth grades, teachers answered six questions from the *Temperament in Middle Childhood Questionnaire* (TMCQ; Simonds & Rothbart, 2004) inhibitory control scale and one question from the CBQ-SF inhibitory control scale, with responses on a 5-point scale ranging from “almost always untrue” to “almost always true.” A sample item from the TMCQ is “can stop him/herself from doing things too quickly.” The items were averaged within-wave to create a scale of inhibitory control, which showed good internal consistency across the waves, α s ranging from .85 to .87 (Tourangeau et al., 2018).

Cognitive flexibility.: Children’s cognitive flexibility was measured through a direct assessment, the Dimensional Change Card Sort task (DCCS; Zelazo, 2006). In this task, children must sort a set of cards according to one set of rules (e.g., by shape) and then according to a different set of rules (e.g., by color). They then sort cards in rounds that switch between these rules. During kindergarten and first grade, the task was administered using physical cards and scores indicate the accuracy of card sorting across rounds. In third and fourth grades, children completed the DCCS on a tablet device and scores incorporate information about accuracy as well as reaction time (Zelazo et al., 2013). The tablet-based assessment was not available during the kindergarten and first grade waves because it was still under development (Tourangeau et al., 2018).

Working memory.: Children’s working memory was directly assessed using the Numbers Reversed task of the Woodcock-Johnson III Cognitive Scales (Blackwell, 2001). In this task, children must recall a series of numbers presented orally and repeat them in reverse order (Blackwell, 2001). Following successful rounds, the string of numbers becomes longer and more difficult up to a maximum of eight digits. The task ends when children incorrectly recall three numeric sequences in a row. We use the *W*-ability score constructed using item response theory, which is recommended for longitudinal analyses (Tourangeau et al., 2018).

Attentional Control—At kindergarten and first grade, teachers reported children’s attentional control with six questions from the attentional focus subscale of the CBQ-SF. Responses were recorded on a 7-point scale ranging from “extremely untrue” to “extremely true.” A sample item is, “This child, when working on an activity, has a hard time keeping her/his mind on it.” In third and fourth grades, the teacher-report included six questions from the attentional focusing subscale of the TMCQ. A sample item from this subscale is “has a hard time paying attention.” Responses were recorded on a five-point scale ranging from “almost always untrue” to “almost always true.” The items were averaged within-wave

to create a scale of attentional control, which showed good internal consistency across the waves, α s ranging from .83 to .96 (Tourangeau et al., 2018).

Social Self-Control—Teachers rated children’s social self-control at all waves using four items adapted from the *Social Skills Rating System* (SSRS; Gresham & Elliott, 1990) related to emotion regulation and social problems solving. A sample item is, “Controls temper in conflict situations with peers.” Teachers’ responses were recorded on a four-point frequency scale ranging from “never” to “very often.” Scores were computed by taking the average of the four items at each wave. This measure showed adequate internal consistency, α s ranging from .80-.82 across the waves used in the analysis (Tourangeau et al., 2018).

Analytic Approach

We conducted two pairs of path models to test whether frequency of regular physical activity and sports participation predict growth in executive functions and related skills from kindergarten to first grade and from third grade to fourth grade. We restricted our analyses to these waves because the sports participation indicators were only available at the kindergarten and third grade waves. We conducted models separately for predictions from kindergarten to first grade and from third to fourth grade in order to use the appropriate sample weights for these time periods. We ran four models in total.

For each age, we first modeled the association between regular physical activity and children’s executive functions, attention, and social self-control one year later. In our second model, we added the two sports participation indicators (group and individual sports) to the baseline model. All models controlled for children’s prior levels of executive functions and related skills so that we could predict change in these constructs over time. That is, we controlled for kindergarten skills when predicting to first grade and controlled for third grade skills when predicting to fourth grade. We also controlled for covariates that may be related to both frequency and type of activity and with executive functions and related skills, specifically body mass index (BMI), highest level of parent education, and family income one year prior, as well as a parental report of the child’s general level of physical activity relative to other children their age. The latter is an important control variable in the absence of indicators of disabilities that might predict a child’s activity level (e.g., ADHD or limited mobility) that were not available in the public use dataset. All models also controlled for child gender and child race and ethnicity as assessed at the kindergarten (baseline) wave.

We used sample weights to adjust for attrition and nonresponse at each wave and to ensure that our sample remained nationally representative. We also calculated standard errors using the jackknife replication method, which accommodates sample weights while accounting for clustering within sampling units (i.e., schools; Tourangeau et al., 2018). We conducted all models in Mplus (version 8.2) using maximum likelihood robust estimation and full information maximum likelihood (FIML) methods to account for missing data (Muthén & Muthén, 1998-2017).

Results

Descriptive statistics for all variables in the analysis are shown in Table 1. On average, children engaged in physical activity 5.15 days per week in kindergarten ($SD = 1.87$) and 4.44 days per week in third grade ($SD = 2.18$). More children participated in group sports in third grade (64.5%) compared to kindergarten (52.3%). The percentage participating in individual sports was virtually the same from kindergarten (55.8%) to third grade (55.5%). As expected, children's scores on the direct assessments measuring cognitive flexibility and working memory increased from kindergarten to first grade and from third to fourth grade. The teacher ratings of children's inhibitory control, attention, and social self-control remained relatively stable over time. Table S1 in the supplemental materials displays correlations among physical activity, sports participation, the five skills examined from kindergarten to first grade, and all of the covariates in the models. Table S2 in the supplemental materials presents the same correlations from third grade to fourth grade.

Predicting First Grade Child Outcomes from Kindergarten Physical Activity

The results from the models predicting change in children's executive functions and related skills from kindergarten to first grade from kindergarten physical activity are shown in the top half of Table 2. Of the goodness-of-fit statistics typically calculated for structural equation models, only the SRMR, an absolute measure of fit, is available when using jackknife replicate weights (Muthén & Muthén, 1998-2017). All models showed adequate fit of $SRMR < .08$ (Hu & Bentler, 1998), with SRMR values ranging between .041-.054.

The association between regular physical activity in kindergarten and change in children's executive functions and related skills from kindergarten to first grade was indistinguishable from zero for all outcomes after controlling for prior levels of these skills and other covariates. Participation in group sports in kindergarten, however, predicted children's executive functions and related skills in first grade even after controlling for prior skill levels and other covariates. Group sports participation predicted modest growth in children's inhibitory control ($\beta = 0.03, p < .01$), attentional control ($\beta = 0.03, p < .01$), and social self-control ($\beta = 0.03, p < .05$), but not their cognitive flexibility or working memory (*ns*). Participation in individual sports did not predict growth in children's executive functions and related skills from kindergarten to first grade (*ns*).

Predicting Fourth Grade Child Outcomes from Third Grade Physical Activity

Regular physical activity in third grade predicted modest growth in children's executive functions and attentional control at 4th grade (see bottom half of Table 2). Children's regular physical activity predicted growth in their inhibitory control ($\beta = 0.05, p < .01$), cognitive flexibility ($\beta = 0.03, p < .05$), working memory ($\beta = 0.03, p < .05$), and attentional control ($\beta = 0.03, p < .05$). Physical activity did not predict gains in children's social self-control (*ns*).

Children's participation in group sports in third grade consistently predicted children's gains in executive functions and related skills from 3rd to 4th grades over and above the frequency of their regular physical activity alone. Participation in group sports predicted gains in children's inhibitory control ($\beta = 0.03, p < .05$), cognitive flexibility ($\beta = 0.04, p < .001$),

working memory ($\beta = 0.03, p < .05$), attentional control ($\beta = 0.03, p < .05$), and social self-control ($\beta = 0.03, p < .05$). Participation in individual sports did not predict gains in any outcomes over and above whether they engaged in regular physical activity or in group sports (*ns*).

Discussion

Using a nationally representative, longitudinal sample of elementary school children, we found that both the frequency and type of children's regular physical activity uniquely predicted growth in children's executive functions and related skills, albeit modestly. These findings align with a growing body of evidence that regular physical activity may promote these skills through two pathways: increased fitness which in turn benefits neurological functioning (Donnelly et al., 2016) and engagement in activities involving complex social, motor, and cognitive demands (Tompsonski & Pesce, 2019). Though our study did not examine biological mechanisms and so cannot confirm the first pathway, our findings were consistent with this pathway operating in middle childhood. Regarding the second pathway, our findings offer support for it in both early and middle childhood.

From kindergarten to first grade, only engagement in group sports predicted growth in children's inhibitory control, attention, and social self-control. These results are consistent with other studies finding that engagement in physical activity does not systematically predict executive functions in early childhood (Cook et al., 2019; McNeill et al., 2020). The brain develops rapidly during early childhood and accounts for a lifetime maximum of glucose consumption, indicating a heightened metabolic tradeoff between brain and body during this period (Blair et al., 2020; Kuzawa et al., 2014). As a result of this tradeoff, physical activity during early childhood may not have the same benefits for executive functions and related skills as it appears to have in middle childhood. Findings from the current study are consistent with this pathway, but do not confirm it because the study did not assess neural or biological processes. The fact that group sports did predict improvements in inhibitory control, attention, and social self-control provides support for the hypothesis that aspects of such group activities do foster some skills related to executive functions, and more so than individual sports. Therefore, it may be the joint, coordinated sports activities with fellow children that are most predictive of gains in inhibitory control, attentional control, and social self-control.

When the children were just a few years older, both regular physical activity and participation in group sports predicted modest growth in children's executive functions and attention from third grade to fourth grade. These predictions appear to be largely additive—the coefficients for regular physical activity attenuated by only 3-31% once activity indicators were included in the model. Furthermore, these patterns of prediction held across types of measurement (i.e., teacher ratings and direct assessments with children). The only skill at fourth grade that group sports participation predicted that regular physical activity did not was social self-control. This skill does not appear to improve with exercise alone but through situations that involve interaction and coordination with other children.

Group sports thus emerged as a consistent predictor of executive functions, attention, and social self-control. It may be that group sports incorporate unique social and cognitive demands that promote diverse skills for regulating one's attention and behavior across elementary school. Although individual sports may promote motor skills and coordination, they may not require the same kind of adaptation to fluid dynamics that group sports require, instead involving more repetitive and predictable actions (Becker et al., 2018).

The findings from this study have implications for the kinds of activities that can promote executive functions and related skills. Though the effect sizes were small, they occurred as part of children's regular daily activities rather than part of interventions explicitly targeting physical activity or executive functions. The idea that children's daily activities are primary drivers of their development aligns with the bioecological model (Bronfenbrenner & Morris, 2006), which maintains that it is children's sustained interaction with their environments that support development over time. The empirical literature has confirmed that the development of executive functions and other cognitive skills are influenced by children's environments (e.g., Blair & Raver, 2012). The current study suggests that children's regular activities, as proximal contexts for development, have the potential to enhance development of their executive functions and related skills. Because this study observed such changes across early and middle childhood, it suggests that executive functions and related skills are malleable to the influences of daily activities across these ages. Although the development of executive functions is especially malleable in early childhood, this malleability continues across childhood (Zelazo & Carlson, 2012).

Given the benefits of physical activity and group sports for children's development, not only for their executive functions but also their cardiovascular health (Proudfoot et al., 2019) and social skills (Eime et al., 2013), practitioners and policymakers may consider encouraging more opportunities for physical activity and sports participation. Regular opportunities for physical activity are critical for children to engage in the recommended 60 minutes of moderate to vigorous physical activity per day for children 6-18 and 180 minutes of light, moderate, or vigorous activity for children ages 3-5 (U.S. Department of Health and Human Services, 2018). Despite these recommendations, most children in the United States are under-active (Katzmarzyk et al., 2016) and likely need more opportunities to engage in physical activity.

Strengths and Limitations

This study had several strengths. First, it used a nationally representative sample of children and utilized data from two developmental periods, uncovering differences in early childhood and middle childhood for the same cohort of children. Second, the sources for the independent (parent report) and dependent variables (teacher report and direct child assessment) were distinct, thereby avoiding shared rater variance. Third, the analyses controlled for children's prior level of executive functions, attention, and social self-control, indicating that predictions from physical activity and group sports participation indicated growth in these skills from one year to the next. Though the effect sizes are small, even small effects at the population-level can impact population health and development.

A main limitation of this study is our reliance on parental reports of physical activity rather than objective measurement of children's activity levels. Without direct observations of children's physical activity levels, we could not rule out the possibility that sports participation provided opportunity for engagement in more intense or sustained physical activity rather than providing opportunities to engage children's executive functions and related skills. If this were the case, however, we would expect both group sports and individual sports to increase physical activity levels and see both provide an additive prediction above that of the frequency regular physical activity alone, though participation in individual sports did not. It is possible that playing with other children via group sports may be more effective in promoting physical activity levels in elementary school aged children than individual sports. However, the finding that group sports promoted growth in social self-control, which likely arises from complex social interaction rather than from increased physical activity, lends support to the notion that group sports incorporates fluid social dynamics which engage these skills.

Future Directions

The findings from this study present future directions for research. Though the effect sizes for participation in group sports were small (ranging between .02 and .04), future studies may clarify and more precisely estimate the magnitude of these effects. For example, the frequency of participation in group sports may matter (Verburgh et al., 2016). Frequent and sustained participation in group sports over a year would likely have stronger effects on children's executive functions and related skills than less regular participation. The survey responses in the ECLS-K:2011 dataset only allowed analysis with dichotomous indicators, but future studies should examine the frequency and intensity of engagement in group sports.

The extent to which activities are structured may also matter. Activities structured and led by adults may be more effective in promoting these skills than unstructured activities that prompt management of peer relationships. Adults can provide scaffolding and create opportunities for children to practice skills like attentional or inhibitory control, though the quality of programs and activities might determine the extent to which they promote these skills. Beyond structured activities, children may have more opportunities to learn conflict resolution and other skills for social self-control when playing among themselves. We could not test these possibilities in the present study but it is a ripe area for future research.

A final area for future research is the contexts in which these activities occur. The survey data from the ECLS-K: 2011 did not provide information about whether children's physical activity occurred at home or at school, and whether it was coordinated by parents, peers, or educators. These developmental and social contexts may be equally or differentially relevant for children's executive functions and related skills. Future studies should also test whether these results generalize outside of the U.S. or other WEIRD (western, educated, industrialized, rich, and democratic) countries, as most children around the world grow up in non-WEIRD countries.

Conclusion

Our findings confirmed that both the amount and type of regular physical activity show longitudinal associations with executive functions, attention, and social self-control in a national sample of school-aged children in the U.S. We found differences across developmental periods and clarified that physical activity and participation in group sports shows additive associations with these skills. In light of these findings, practitioners and policymakers should consider encouraging more opportunities for physical activity and sports participation. This would be a step toward the goal of educating the whole child (Liew, 2012) and a recognition that the physical, cognitive, and social parts of ourselves are deeply intertwined (Diamond, 2007, 2010).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements:

This research was supported by a grant from the National Science Foundation (1519686 awarded to E. T. Gershoff & R. L. Crosnoe) and by grants from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (P2CH042849 and T32HD007081 awarded to the Population Research Center at the University of Texas at Austin).

Data Availability Statement:

This study used the 4th grade longitudinal public use file of the Early Childhood Longitudinal Study, Kindergarten Class of 2010-11. These data are publicly available data from the National Center for Education Statistics at <https://nces.ed.gov/ecls/kindergarten2011.asp>. See Tourangeau et al. (2018) for study details.

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Research Highlights

- Regular physical activity predicts growth in executive functions (EFs) and related skills from third to fourth grade, but not from kindergarten to first grade.
- Participation in group sports predicts growth in EFs, attention, and social self-control in early and middle childhood.

Table 1

Weighted Descriptive Statistics ($N = 18,174$)

	Kindergarten	First grade	Third grade	Fourth Grade
	% or M (SD)	% or M (SD)	% or M (SD)	% or M (SD)
Male	51.10%	-	-	-
Child Race/Ethnicity				
Non-Hispanic White	46.70%	-	-	-
Hispanic (any race)	25.20%	-	-	-
Asian	8.50%	-	-	-
Two or more races	4.50%	-	-	-
American Indian/Alaska Native	0.92%	-	-	-
Native Hawaiian/Pacific Islander	0.64%	-	-	-
Parental income category (median)	\$45,000-50,000	-	\$50,000-55,000	-
Parent education	4.59 (1.88)	-	4.73 (1.95)	-
Body mass index (BMI)	16.62 (2.47)	-	18.63 (4.00)	-
Activity level relative to other children	2.60 (.79)	-	2.57 (.84)	-
Number of days per week physically active	5.15 (1.87)	-	4.44 (2.18)	-
Sports participation				
Group sports	52.30%	-	64.50%	-
Individual sports	55.80%	-	55.50%	-
Executive functions (EFs)				
Inhibitory control	5.06 (1.29)	5.07 (1.28)	3.69 (0.82)	3.74 (0.81)
Cognitive flexibility	15.17 (2.76)	16.08 (2.33)	7.22 (1.07)	7.66 (0.94)
Working memory	449.73 (30.35)	469.79 (25.21)	490.08 (21.60)	497.70 (20.93)
EF-related skills				
Attentional control	4.90 (1.33)	4.87 (1.29)	3.49 (1.12)	3.54 (1.11)
Social self-control	3.18 (0.63)	3.22 (.62)	3.27 (.62)	3.28 (0.60)

Table 2

Path models estimating children’s executive functions and related skills at first grade and fourth grade from physical activity and sports participation one year earlier

Predictors from kindergarten	Executive functions and related skills at first grade																			
	Inhibitory control			Cognitive flexibility			Working memory			Attentional control			Social self-control							
	b	SE	β	b	SE	β	b	SE	β	b	SE	β	b	SE	β					
Model 1																				
Number of days	0.00	0.01	-0.01	-0.01	0.01	-0.01	0.05	0.10	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00				
Model 2																				
Number of days	0.00	0.01	-0.01	0.00	0.01	-0.01	0.02	0.10	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00				
Group sports	0.08	**	0.03	0.11	0.06	0.02	0.87	0.46	0.02	0.08	**	0.03	0.03	0.03	*	0.02				
Individual sports	0.00	0.03	0.00	-0.06	0.04	-0.01	0.83	0.56	0.02	0.01	0.03	0.00	-0.01	0.01	-0.01	-0.01				
Executive functions and related skills at fourth grade																				
Predictors from third grade	Inhibitory control			Cognitive flexibility			Working memory			Attentional control			Social self-control							
	b	SE	β	b	SE	β	b	SE	β	b	SE	β	b	SE	β					
	Model 3																			
Number of days	0.02	**	0.01	0.05	0.01	*	0.01	0.03	0.03	0.26	*	0.12	0.03	0.02	0.01	0.03	0.00	0.00	0.02	
Model 4																				
Number of days	0.02	**	0.01	0.04	0.01	*	0.01	0.03	0.03	0.23	*	0.12	0.02	0.01	*	0.01	0.03	0.00	0.00	0.01
Group sports	0.05	*	0.02	0.03	0.09	***	0.02	0.04	0.04	1.17	*	0.56	0.03	0.07	*	0.03	0.03	0.04	*	0.02
Individual sports	0.03	0.02	0.02	0.02	-0.02	0.02	-0.01	0.02	-0.01	0.52	0.56	0.01	0.04	0.03	0.02	0.01	0.02	0.01	0.02	0.01

Note. All models account for clustering within sampling units and included the following covariates: skill level one year earlier, parental education and income, child activity level relative to others their age, and children’s race and gender.

* $p < .05$
 ** $p < .01$
 *** $p < .001$